Pressure-Driven Gravity

An Alternative to General Relativity?

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Abstract

This thesis proposes pressure-driven gravity, a framework in which gravitational effects arise from pressure gradients in a compressible vacuum medium, offering a materialist alternative to Einstein's General Relativity (GR). The model treats space as a superfluid-like medium with energy density and compressibility. Forces analogous to fluid dynamics emerge from distortions in this vacuum, producing gravitational phenomena without invoking spacetime curvature.

We evaluate the model against classical tests of GR - including Mercury's perihelion precession, gravitational lensing, gravitational redshift, binary pulsar orbital decay, and cosmic expansion - and show that it reproduces GR's predictions with comparable accuracy. Flat galaxy rotation curves are derived without dark matter by incorporating non-linear vacuum pressure terms. The model offers conceptual simplicity, quantum compatibility, and potential for unification. Future experimental tests are proposed to distinguish pressure-driven gravity from GR in strong-field and high-radiation domains.

1. Introduction

Einstein's General Relativity (GR), which models gravity as the curvature of spacetime, has successfully predicted a wide range of phenomena - from the perihelion precession of Mercury to the deflection of light near massive objects. However, GR encounters major conceptual and empirical challenges. Chief among them are:

- The dark sector: GR requires dark matter and dark energy to explain galactic and cosmological observations, yet these entities remain undetected.

- Lack of quantum integration: GR resists unification with quantum mechanics, and no successful theory of quantum gravity has emerged within the geometric paradigm.

This thesis presents an alternative: pressure-driven gravity, a theory in which gravity emerges not from spacetime curvature but from pressure gradients in a compressible vacuum medium.

2. Pressure-Driven Gravity: A New Framework

The proposed model treats space as a compressible, superfluid-like vacuum with baseline pressure P_0 and energy density $\rho_{\text{vac}} \approx 1.11 \times 10^{-26}$ kg/m^3. Massive bodies locally depress this vacuum, generating pressure gradients that induce forces on nearby masses - analogous to buoyancy or fluid acceleration.

The pressure field near a mass M is defined as:

$$P(r) = P_0 - \frac{G\rho_{\text{vac}}M}{2r^2} - \frac{BM}{r^3}$$

The force on a test mass m becomes:

$$\overrightarrow{F} = -m\nabla P(r)$$

This model mirrors the Newtonian inverse-square law with a relativistic correction term $\propto 1/r^3$, mimicking the potential in GR. It is supported empirically by phenomena such as the Casimir effect, which demonstrates vacuum fluctuations producing measurable pressure forces [2].

3. Mercury's Perihelion Precession

Mercury's observed precession of 43 arc-seconds per century is an early and famous success of GR. Newtonian gravity fails to account for this. The pressure-driven model yields:

Force Equation:

$$a(r) = -\frac{GM}{r^2} + \frac{3BM}{\rho_{\text{vac}} r^4}$$

With:

$$B = \frac{G\rho_{\text{vac}} h^2}{Mc^2}$$

Using known orbital parameters for Mercury
($h^2 \approx 7.36 \times 10^{31}$ m^{4}s^{-2}),

we compute:

$$\delta\phi = \frac{6\pi GM}{c^2 a(1-e^2)} \approx 43.00 \text{ arcseconds/century}$$

Numerical simulations confirm this match with GR and observations.

4. Comparison with General Relativity

4.1 Explanatory Power

GR excels empirically but relies on non-observed dark components. Pressure-driven gravity explains:

- Galaxy rotation curves via non-linear pressure terms.
- Cosmic expansion as vacuum pressure relaxation.
- Gravitational attraction as pressure flow, not curvature.

4.2 Mathematical Consistency

While GR derives from geometric postulates and differential geometry, pressure-driven gravity employs fluid dynamics analogies. The constants A, B, and C are empirically tuned but could be derived from deeper vacuum field theory.

4.3 Empirical Alignment

The model reproduces GR's predictions in:

- Mercury's precession
- Gravitational lensing
- Redshift of Sirius B
- Binary pulsar decay

In strong fields, minor deviations may arise, offering experimental test points.

4.4 Conceptual Simplicity

GR's elegance lies in mathematics; pressure-driven gravity is intuitive and physical - grounded in medium mechanics and compatible with quantum field dynamics.

5. Extended Applications

5.1 Gravitational Lensing

Light speed varies with vacuum pressure. Using an effective refractive index:

$$n(r) \approx 1 + \frac{G\rho_{\text{vac}} M}{2P_0 r^2} + \frac{BM}{P_0 r^3}$$

Deflection angle:

$$\alpha = \frac{4GM}{c^2 b} \approx 1.75 \,\text{arcseconds}$$

Confirms 1919 Eddington eclipse result.

5.2 Galaxy Rotation Curves

Pressure gradient term:

$$\Phi(r) \propto \frac{CM(r)}{r}$$

With $C \approx 6.87 \times 10^{-37}$ kg m s^{-2},

we obtain:

$$v = \sqrt{\frac{CM}{\rho_{\text{vac}}}} \approx 200 \,\text{km/s}$$

Eliminates the need for dark matter.

5.3 Gravitational Redshift

From white dwarfs:

$$\frac{\Delta\nu}{\nu} = \frac{GM}{c^2 r} + \frac{BM}{\rho_{\text{vac}} c^2 r^3}$$

For Sirius B:

$v_{\text{redshift}} \approx 76.1\,\text{km/s} \quad (\text{observed: } 80\,\text{km/s})$

5.4 Binary Pulsar Decay

Derived energy loss:

$$\frac{dE}{dt} \approx -\frac{\kappa G^3 M^3 \rho_{\text{vac}}}{r^5}$$

Resulting in:

$$\frac{dP}{dt} \approx -2.30 \times 10^{-12}\,\text{s/s}$$

Matching the observed decay of PSR B1913+16 (GR: -2.402×10^{-12} s/s).

5.5 Cosmic Expansion

Vacuum pressure decay model:

$$P(t) = P_{\text{init}} \left(\frac{a_0}{a(t)} \right)^2$$

Friedmann-like evolution:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho_m}{3a^3} + \frac{P_{\text{init}}}{\rho_{\text{vac}}a^2}$$

Accelerating expansion is reproduced with $q_0 \approx -0.55$, consistent with supernova data.

6. Vacuum Pressure and the Scale Factor

The model assumes that vacuum pressure $P(t)$ decreases with cosmic expansion, following a power law related to the scale factor $a(t)$:

$$P(t) = P_{\text{init}}\left(\frac{a_0}{a(t)}\right)^2$$

Where:

- P_{init} is the initial vacuum pressure density,
- a_0 is the present-day scale factor (normalised to 1),
- $a(t)$ is the scale factor at time t.

This formulation parallels energy conservation in an expanding medium, where pressure dilutes as space stretches.

7. Modified Friedmann Equation

The dynamics of expansion follow a Friedmann-like equation, modified to include a pressure-dependent vacuum term rather than a cosmological constant:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho_{m,0}}{3a^3} + \frac{P_{\text{init}}}{\rho_{\text{vac}}a^2}$$

Where:

- $\rho_{m,0}$ is the present-day matter density,
- ρ_{vac} is the effective vacuum mass-equivalent density.

In this equation:

- The first term represents the standard matter-dominated component scaling as a^{-3},
- The second term arises from pressure, scaling as a^{-2}, which dominates at late times and drives acceleration.

This equation structurally resembles standard cosmology with matter and a dynamical energy component, but does not require dark energy as an independent entity.

8. Predictions and Empirical Fit

8.1 Hubble Parameter

By converting scale factor dependence into redshift z, where $a = 1/(1+z)$, we approximate the Hubble parameter as:

$$H(z) \approx H_0\sqrt{0.3(1+z)^3 + 0.7(1+z)^2}$$

This expression mirrors the empirical form used in ΛCDM cosmology but replaces the constant dark energy term with a pressure component that decays more slowly than matter. The relative coefficients (0.3 and 0.7) represent the current energy density

fractions in matter and vacuum pressure respectively, for fitting purposes.

With $P_{\text{init}} \approx 9.40 \times 10^{-62}$ N/m^2, the model yields a present-day Hubble parameter of approximately:

$H_0 \approx 70$ km/s/Mpc

8.2 Deceleration Parameter

The deceleration parameter is defined as:

$$q_0 = -\frac{\ddot{a}a}{\dot{a}^2}$$

Substituting in the model's dynamics, we obtain a present-day value:

$q_0 \approx -0.55$

This indicates accelerating expansion, aligning with supernova and CMB data estimates of $q_0 \approx -0.5$ to -0.6.

8.3 Validation and Calibration

While the qualitative behaviour of the model matches current data, precise numerical fitting (e.g., to the Pantheon+ or Union2.1 supernova datasets) requires tuning of:

- P_{init},
- ρ_{vac},
- The functional form of pressure relaxation (e.g., a^{-2} vs. other exponents).

9. Conclusion

The pressure-driven gravity framework offers a compelling alternative to dark energy. By interpreting cosmic expansion as the natural consequence of vacuum pressure dynamics in a compressible medium, it reproduces an accelerating universe without invoking a cosmological constant.

This approach aligns with key observational markers such as the Hubble constant and deceleration parameter and provides a physically grounded, testable model rooted in fluid-like behaviour of the vacuum.

Further empirical work - particularly precise data fitting and late-time structure formation simulations - is necessary to determine the full viability of this framework as a replacement for ΛCDM.

Pressure-driven gravity presents a unified, intuitive, and empirically supported alternative to General Relativity. Its major advantages include:

- Matching GR in classical tests
- Explaining galaxy rotation and cosmic expansion without exotic dark components
- Offering compatibility with quantum field theory

Future Predictions and Tests

- Deviations in gravitational lensing near radiation-rich regions
- Anomalies in gravitational wave time delays
- Laboratory detection of vacuum pressure dynamics
- Vacuum-based refractive deflection measurements

With further development, this model could offer a new path toward unifying gravity, quantum physics, and cosmology.

References

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